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(54) Title of the invention: Catadioptric Optical System

(57) Abstract

Purpose: to achieve reduction in the diameter of a concave mirror without deteriorating performance of an optical system.

Configuration: There is provided a catadioptric optical system. Here, a third lens group G3 having a positive refracting power in a first imaging optical system which forms an intermediate image on a first surface at least includes, in the following order from the first surface side, a tenth lens group G10 having a positive refracting power, an eleventh lens group G11 having a negative refracting power, and a twelfth lens group G12 having a positive refracting power. A fourth lens group G4 has a concave mirror and a negative lens component whose concave surface faces the first surface side. The light from the first surface is guided in the following order of the tenth lens group G10, the eleventh lens group G11, the twelfth lens group G12, the fourth lens group G4, the twelfth lens group G12, the eleventh lens group G11 and the tenth lens group G10. A synthetic magnification of the first image optical system and the second image optical system is a reducing magnification.

What is claimed is:

Claim 1

A catadioptric optical system comprising:

a first imaging optical system which forms an intermediate image on a first surface;

a second imaging optical system which forms an image of the intermediate image on a second surface; and

an optical path deflecting member which is disposed in an optical path from the first imaging optical system to the second imaging optical system to guide light from the first imaging optical system to the second imaging optical system,

wherein the first imaging optical system at least includes a third lens group G3 having a positive refracting power as a whole and a fourth lens group G4 which has a concave mirror and a negative lens component whose concave surface faces the first surface,

wherein the third lens group G3 at least includes, in the following order from the first surface side, a tenth lens group G10 having a positive refracting power, an eleventh lens group G11 having a negative refracting power, and a twelfth lens group G12 having a positive refracting power,

wherein the light from the first surface is guided in the following order of the tenth lens group G10, the eleventh lens group G11, the twelfth lens group G12, the fourth lens group G4, the twelfth lens group G12, the eleventh lens group G11 and the tenth lens group G10, and

wherein a synthetic magnification of the first image optical system and the second image optical system is a reducing magnification.

Claim 2

The catadioptric optical system according to claim 1, wherein the first imaging optical system has a reducing magnification and the second imaging optical system has a reducing magnification.

Claim 3

The catadioptric optical system according to claim 1 or 2, wherein the second imaging optical system includes a fifth lens group G5 having a positive refracting power and a sixth lens group G6 having a positive refracting power.

Claim 4

The catadioptric optical system according to claim 3, wherein an aperture stop is disposed in an optical path between the fifth lens group G5 and the sixth lens group G6.

Claim 5

The catadioptric optical system according to any one of claims 1 to 4, wherein the first imaging optical system has a seventh lens group G7 which is disposed in an optical path between the first surface and the third lens group G3, and wherein the seventh lens group G7 has, in the following order from the first surface, a front group having a positive refracting power and a rear group having a negative refracting power.

Claim 6

The catadioptric optical system according to any one of claims 1 to 5, wherein, assuming that an object on the first surface has a height Y0 and the intermediate image formed by the first imaging optical system has an image height Y1, the catadioptric optical system satisfies the following condition, $0.4 < | Y0/Y1 | < 1.2$.

Claim 7

The catadioptric optical system according to any one of claims 1 to 5, wherein optical materials forming the second imaging optical system are at least two kinds of optical materials having dispersion values different from each other.

Claim 8

The catadioptric optical system according to any one of claims 1 to 5 or claim 7, wherein the fifth lens group G5 in the second imaging optical system includes a negative lens component made of high dispersion glass and a positive lens component made of low dispersion glass, and the sixth lens group G6 in the second imaging optical system includes a positive lens component made of low dispersion glass.

Claim 9

The catadioptric optical system according to any one of claims 1 to 8, wherein a second optical path deflecting member for deflecting light from the first surface is disposed between the first surface and the third lens group G3 in the first imaging optical system, to place the first surface and the second surface in parallel to each other.

Claim 10

The catadioptric optical system according to claim 9, wherein a normal line of the first surface and a normal line of the second surface are orthogonal to a direction of gravity.

Claim 11

The catadioptric optical system according to any one of claims 1 to 8, wherein an optical path deflecting member is disposed between the fifth lens group G5 and the sixth lens group G6 in the second imaging optical system, to place the first surface and the second surface in parallel to each other.

Claim 12

The catadioptric optical system according to claim 12, wherein the first surface and the second surface are disposed horizontally, and the first surface is positioned above the second surface.

Claim 13

The catadioptric optical system according to any one of claims 1 to 12, wherein a field stop for changing the size of an image-forming field on the second surface is disposed on a position of the intermediate image which is formed between the first imaging optical system and the second imaging optical system.

Claim 14

The catadioptric optical system according to any one of claims 1 to 13, wherein a special filter is disposed near the concave mirror in first imaging optical system or in the optical path of the second imaging optical system.

Claim 15

The catadioptric optical system according to claim 14, wherein an aperture stop is disposed in the optical path of the second imaging optical system or near the concave mirror in the first imaging optical system.

Detailed Description of the Invention

[0001]

Field of the Invention

The present invention relates to a projection optical system for a projection exposure apparatus such as a stepper which is used when a semiconductor device or a liquid crystal display device, for example, is manufactured in a photolithography process. In particular, the present invention relates to a catadioptric projection optical system using a reflection system as an element of its optical system.

[0002]

Prior Art

When a semiconductor device, a liquid crystal display device, or the like is manufactured in a photolithography process, there has been used a projection

exposure apparatus in which a pattern image of a reticle (or photomask, for example) is reduced by way of a projection optical system to a magnification of about 1/4 to 1/5, for example, so as to be exposed onto a wafer (or a glass plate, or the like) coated with photoresist. As the projection exposure apparatus, a one-shot exposure method such as a stepper has been mainly used in the related art.

[0003]

Recently, in the manufacture of semiconductors and the manufacture of semiconductor chip mounting substrates, as patterns formed in the semiconductors become finer, a higher resolution has been required for the exposure apparatus used for projecting their patterns onto the substrates. In order to satisfy this requirement, the wavelength of a light source for exposure (exposure wavelength) has to be shortened or the numerical aperture NA of the projection optical system has to be increased. However, when the exposure wavelength is short, kinds of practically usable optical glass materials are limited due to absorption of illumination light, thereby making it difficult to constitute a projection optical system by a refraction system only. In particular, when the wavelength is 300 nm or shorter, practically usable glass materials are limited to synthetic quartz and fluorite alone.

[0004]

On the other hand, though there have been attempts to constitute a projection optical system by a reflection system alone, the projection system tends to have a larger size while its reflective surface has to be made aspheric in this case. However, it is quite difficult to manufacture a highly accurate aspheric surface with a large size. Accordingly, there have been proposed a variety of techniques for constituting a projection optical system by a so-called catadioptric optical system in which a reflection system and a refraction system made of a kind of optical glass which can tolerate the exposure wavelength used are combined together.

[0005]

As an example thereof, catadioptric optical systems in which an optical system including a single concave mirror and a refraction optical system are combined together so as to project a reticle image with a predetermined reducing magnification are disclosed, for example, in US Patent No. 4,779,966 and Japanese Unexamined Patent Publication No. H4-234722. The catadioptric optical system disclosed in the above-mentioned US Patent No. 4,779,966 includes, in the following order from its object side, a refraction optical system and a catadioptric optical system for re-imaging an intermediate image formed from the refraction optical system.

[0006]

Further, the optical system disclosed in Japanese Unexamined Patent Publication No. H4-234722 includes, in the following order from its object side, a completely symmetric catadioptric optical system and a refraction optical system for

re-imaging, with a reduced magnification, an intermediate image formed from the catadioptric optical system.

[0007]

Problems to Be Solved

In the catadioptric optical systems disclosed in the above-mentioned US Patent No. 4,779,966 and Japanese Unexamined Patent Publication No. H4-234722, only lens components having a negative refracting power are used as refractive optical members in the catadioptric optical system including a concave mirror. Accordingly, the diameter of a luminous flux reaching the concave mirror from the object (intermediate image) continuously increases, thereby making it difficult to reduce the diameter of the concave mirror itself.

[0008]

In addition to the above described problems, in particular, in the catadioptric optical system disclosed in the above-mentioned US Patent No. 4,779,966, the numerical aperture of the optical system near the image has to be increased in order to increase the numerical aperture on the image side. In this case, since it is necessary for the luminous flux incident on the concave mirror in the catadioptric optical system disposed on the image side to have an increased diameter, the diameter of this concave mirror increases. Further, in the catadioptric optical system disclosed in the above-mentioned US Patent No. 4,779,966, in conjunction with its reducing magnification, the optical path from the concave reflective mirror M_2 to the wafer cannot be made long, whereby the number of refractive lenses disposed in this optical path cannot be increased and a sufficient image-forming performance may not be attained. Also, for this reason, the distance between the wafer and the end surface of the optical device nearest to the wafer, namely, the working distance on the wafer side cannot be made long.

[0009]

On the other hand, in the catadioptric optical system disclosed in Japanese Unexamined Patent Publication No. H4-234722, an optical system using a single path for both incoming and outgoing paths constitutes a completely symmetric optical system. This configuration minimizes the aberration occurring in the optical system so as to reduce the burden of the aberration correction on the subsequent catadioptric optical system. However, since the catadioptric optical system constitutes the symmetric optical system, the working distance near the first surface cannot be made long.

[0010]

In order to overcome the foregoing problems, a second object of the present invention is to provide a catadioptric optical system which is configured such that, without deteriorating performances of its optical system, the diameter of its concave

mirror can be reduced. Further, another object of present invention is to provide a catadioptric optical system which secures a sufficient working distance and realizes a large numerical aperture while reducing the diameter of the concave mirror.

[0011]

Solution

In order to attain the above-mentioned objects, there is provided a catadioptric optical system including: a first imaging optical system which forms an intermediate image on a first surface; a second imaging optical system which forms an image of the intermediate image on a second surface; and an optical path deflecting member which is disposed in an optical path from the first imaging optical system to the second imaging optical system to guide light from the first imaging optical system to the second imaging optical system, wherein the first imaging optical system at least includes a third lens group G3 having a positive refracting power as a whole and a fourth lens group G4 which has a concave mirror and a negative lens component whose concave surface faces the first surface side, wherein the third lens group G3 at least includes, in the following order from the first surface side, a tenth lens group G10 having a positive refracting power, an eleventh lens group G11 having a negative refracting power, and a twelfth lens group G12 having a positive refracting power, wherein the light from the first surface is guided in the following order of the tenth lens group G10, the eleventh lens group G11, the twelfth lens group G12, the fourth lens group G4, the twelfth lens group G12, the eleventh lens group G11 and the tenth lens group G10, and wherein a synthetic magnification of the first image optical system and the second image optical system is a reducing magnification.

[0012]

Description of Embodiments

According to the configuration of the present invention as described above, since the third lens group G3 disposed in front of the concave mirror has the positive refracting power, a convergence effect is given to the luminous flux radiated from the first surface, and the luminous flux incident to the fourth lens group G4 is narrowed. Thus, the concave mirror in the fourth lens group G4 is reduced in size. Further, the catadioptric optical system is configured so that the third lens group G3 includes the tenth lens group G10 having the positive refracting power, the eleventh lens group G11 having the negative refracting power, and the twelfth lens group G12 having the positive refracting power, thereby preferably correcting the various aberrations. Also, with such a configuration, the length of the first imaging optical system can be decreased.

[0013]

Further, according to the above-mentioned configuration of the present invention, since the working distance near the first surface can be increased, the

optical path deflecting member can be easily inserted therein. Preferably, the optical path deflecting member has only a function of simply bending the optical path. When such an optical path deflecting member is used, unlike a beam splitter, the optical path deflecting member does not necessarily have a function of separating the luminous flux, and thus, the loss in optical quantity can be suppressed to almost 0%, and occurrence of flare can become quite scarce. With the optical path deflecting member having only the function of bending the optical path, the aberration which may result from uneven characteristics of a light-dividing surface of the beam splitter used and the aberration which may result from changes in the characteristics of the light-dividing surface due to thermal absorption do not occur.

[0014]

More preferably, the optical path deflecting member is disposed near the intermediate image formed by the first imaging optical system. According to this configuration, the influence of eccentric errors upon bending of the optical path can become very small. For example, in a case where an angular error is generated in the optical path deflecting member, the second imaging optical system may become eccentric with respect to the first imaging optical system. However, the image formed on the second surface only shifts with respect to the first surface, thereby hardly influencing the image-forming performance.

[0015]

In the present invention, since the second imaging optical system does not have the concave mirror, the working distance on the image side of the second imaging optical system can be sufficiently secured even under a large numerical aperture. Further, in the present invention, the second imaging optical system may preferably include the fifth lens group G5 having a positive refracting power and the sixth lens group G6 having a positive refracting power. Further, in the present invention, an aperture stop may preferably be disposed in an optical path between the fifth lens group G5 and the sixth lens group G6. When this aperture stop is a variable aperture stop, the coherence factor (σ value) can be adjusted.

[0016]

Here, as a technique for increasing the depth of focus so as to improve the resolution, for example, a phase shift method in which the phase of a predetermined portion in the pattern of the reticle is shifted from the phase of the other portion is proposed in Japanese Patent Publication No. S62-50811. The present invention is advantageous in that the effects of this phase shift method can be further improved since the coherence factor (σ value) can be adjusted.

[0017]

In the present invention, it is preferable that the first imaging optical system has a reduction magnification and the second imaging optical system has a reduction

magnification. As the refracting powers are thus arranged, the optical systems can be simply configured. Also, in the present invention, it is preferable that the first imaging optical system has the seventh lens group G7 disposed in an optical path between the first surface and the third lens group G3. Preferably, this seventh lens group G7 functions to correct asymmetric aberrations which cannot be corrected by the first imaging optical system and the second imaging optical system, in particular, such as distortion aberration and chromatic aberration of magnification. Preferably, this seventh lens group G7 has, in the following order from the first surface side, a front lens group with a positive refracting power and a rear lens group with a negative refracting power. According to this configuration, the seventh lens group G7 can favorably maintain its telecentric characteristic, while reducing its diameter as a whole.

[0018]

In the present invention, preferably, optical materials forming the second imaging optical system may be at least two kinds of optical materials having dispersion values different from each other. Accordingly, the chromatic aberration correcting effect can be improved. Further, in the present invention, preferably, the fifth lens group G5 in the second imaging optical system includes a negative lens component made of high dispersion glass and a positive lens component made of low dispersion glass, while the sixth lens group G6 in the second imaging optical system includes a positive lens component made of low dispersion glass. According to this configuration, the chromatic aberration correcting effect can be further improved.

[0019]

Further, in the present invention, the following condition is satisfied:

$$0.4 < |Y0/Y1| < 1.2 \qquad (1)$$

Here, Y0 is the height of an object on the first surface and Y1 is the height of the intermediate image formed by the first imaging optical system. Within this condition range, the optical system can be simply configured. When this ratio is below the lower limit of condition (1), the reduction magnification of the first imaging optical system becomes so large that it may become difficult to perform exposure in a wide range. By contrast, when this ratio exceeds the upper limit of condition (1), the reduction magnification of the first group becomes so small that the concave mirror may not be reduced. Here, better results can be obtained if the lower and upper limits are set to 0.6 and 1.0, respectively.

[0020]

Further, the present invention preferably satisfies the following condition:

$$1/10 < |\beta| < 1.2 \qquad (2)$$

Here, β is the magnification of the catadioptric optical system as a whole. Within this condition range, as in the case of the above-mentioned condition (1), the

optical system can be simply configured. When the absolute value of this magnification is below the lower limit of condition (2), the reduction magnification becomes so large that it may become difficult to perform exposure in a wide range. By contrast, when the absolute value of this magnification exceeds the upper limit of condition (2), the reduction magnification of the catadioptric optical system as a whole becomes so small that it may not be called a reduction projection exposure apparatus any more. Here, better results can be obtained if the lower limit is set to 1/8.

[0021]

Further, the present invention preferably satisfies the following condition:

$P4 < 0$ (3)

Here, P4 is Petzval's sum of the fourth lens group G4. If condition (3) is not satisfied, the luminous flux emitted from the fourth lens group G4 will become greater than that incident thereon, and thus, each lens of the third lens group G3 will have a larger size, which may cause problems. In addition, it is not preferable since the Petzval's sum of the catadioptric optical system itself increases so that the image plane may not be flat any more.

[0022]

Further, the present invention preferably satisfies the following condition:

$P3+P5+P6+P7 < 0$ (4)

Here, P3 indicates Petzval's sum of the third lens group G3, P5 indicates Petzval's sum of the fifth lens group G5, P6 indicates Petzval's sum of the sixth lens group G6, and P7 indicates Petzval's sum of the seventh lens group G7. If condition (4) is not satisfied, the magnification of the catadioptric optical system as a whole increases so that a favorable reduction magnification may not be obtained.

[0023]

Further, the present invention preferably satisfies the following condition:

$| P3+P4+P5+P6+P7| < 0$ (5)

The above condition relates to Petzval's sum of all the elements of the catadioptric optical system. If the condition (5) is not satisfied, the image plane may warp on a plus side, thereby deteriorating its flatness.

[0024]

Also, the present invention preferably satisfies the following condition:

$|P1+P2| < 0$ (6)

Here, P1 is Petzval's sum of the respective elements of the first imaging optical system when a light ray passes therethrough, while P2 is Petzval's sum of the second imaging optical system. P1 and P2 can be expressed as:

$P1 = (2\times P3) + P4 + P7$

$P2 = P5+P6$

If the condition (6) is not satisfied, for example, the flatness of the image plane may be lost, which is not preferable.

[0025]

Preferred Embodiments

Hereinafter, embodiments of a catadioptric optical system in accordance with the present invention will be described with reference to the following drawings. The catadioptric optical system in each embodiment which will be described later is applicable to a projection optical system of exposure apparatuses in which a pattern image formed on a reticle is transferred onto a wafer which is coated with resist.

[0026]

Firstly, with reference to Fig. 1, a schematic configuration of the catadioptric optical system in accordance with the present invention will be explained. In Fig. 1, the luminous flux from a reticle R on a first surface with a height Y0 with respect to an optical axis passes through a third lens group G3 including a tenth lens group G10 having a positive refractive power, an eleventh lens group G11 having a negative refractive power, and a twelfth lens group G12 having a positive refractive power so as to reach a fourth lens group G4 having a first concave mirror M1 and a meniscus component whose concave surface faces the first surface side. In a second embodiment, a first imaging optical system G1 includes the third lens group G3 and the fourth lens group G4. However, in a first embodiment, between the reticle R on the first surface and the third lens group G3, there exists a seventh lens group G7 having an eighth lens group G8 having a positive refractive power and a ninth lens group G9 having a negative refractive power.

[0027]

Here, the luminous flux which has passed through the third lens group G3 reaches the fourth lens group G4. The luminous flux which has reached the fourth lens group G4 is reflected by a concave mirror M_1 in the fourth lens group G4, and then passes through the third lens group G3 again so as to be guided to an optical path bending mirror M_2 as an optical path deflecting member. The optical path bending mirror M_2 is obliquely disposed by an angle of 45° with respect to optical axes of the first and second imaging optical systems G1 and G2. Then, the luminous flux from the first imaging optical systems G1 becomes a converging luminous flux, thereby forming, near the optical path bending mirror M_2, an intermediate image on the reticle R with a height Y1. Subsequently, the luminous flux reflected by the optical path bending mirror M_2 successively passes through a fifth lens group G5 and a sixth lens group G6, which constitutes the second imaging optical system G2, so as to form a secondary image (image of the intermediate image) of the reticle R on a wafer W on a second surface. Here, an aperture stop "a" is disposed between the fifth lens group G5 and the sixth lens group G6.

[0028]

Further, Fig. 2 is a diagram illustrating another arrangement of the catadioptric optical system in accordance with the present invention. In Fig. 2, members having similar functions to those in Fig. 1 are referred to with marks identical thereto. The configuration of Fig. 2 differs from that of Fig. 1 in that an optical path bending mirror M_0, which is used as an optical path deflecting member, is disposed in an optical path between the first surface and the third lens group G3. Here, the optical path bending mirror M_0 is obliquely disposed by an angle of 45° with respect to an optical axis of the third lens group G3 while being orthogonal to the optical path bending mirror M_2. According to this configuration, the luminous flux proceeding by way of the first imaging optical system G_1 and the optical path bending mirror M_2 attains a direction identical to the proceeding direction of the luminous flux from the first surface, whereby the first surface and the second surface can be placed in parallel to each other. Therefore, the configuration of mechanisms for respectively holding and scanning the first and second surfaces can be simplified.

[0029]

In Fig. 2, the optical path bending mirrors M_0 and M_2 may be provided as a united member. In this case, it becomes easy to process reflective surfaces of the optical path bending mirrors M_0 and M_2 which are orthogonal to each other, thereby facilitating the maintenance of their angles. Also, in this case, the optical path bending mirrors M_0 and M_2 can have a smaller size, thereby increasing the degree of freedom in lens arrangement.

[0030]

Further, Fig. 3 is a diagram illustrating still another arrangement of the catadioptric optical system in accordance with the present invention. In Fig. 3, members having similar functions to those in Fig. 1 are referred to with marks identical thereto. The configuration of Fig. 3 differs from that of Fig. 1 in that an optical path bending mirror M_3, which is used as an optical path deflecting member, is obliquely disposed between the fifth lens group G5 and the sixth lens group G6 in a second imaging optical system, with respect to an optical axis of the fifth lens group G5 (with respect to an optical axis of the sixth lens group G6) by an angle of 45°. According to this configuration, the luminous flux emitted from the lens group G_{22} so as to reach the second surface attains a travelling direction identical to the travelling direction of the luminous flux incident on the first imaging optical system from the first surface, whereby the first surface and the second surface can be placed in parallel to each other. Therefore, the configuration of mechanisms for respectively holding and scanning the first and second surfaces can be simplified.

[0031]

Further, in the example shown in Fig. 3, the optical path bending mirrors M_2 and M_3 are disposed such that the travelling direction of the luminous flux directed from a tenth lens group G10 in the first imaging optical system G1 to the optical path bending mirror M_2 and the travelling direction of the luminous flux directed from the optical path bending mirror M_3 in the second imaging optical system G2 to the sixth lens group G6 are directed opposite to each other, whereby the catadioptric optical system itself can be made compact. In particular, according to this configuration, the distance between the first surface and the second surface can be shortened, thereby reducing the size of the exposure apparatus as a whole. Further, in the example shown in Fig. 3, since the optical path bending mirror M_2 is disposed near the intermediate image formed by the first imaging optical system, the size of the optical path bending mirror M_2 can be reduced, thereby increasing the degree of freedom in arranging the elements of the optical system.

[0032]

Further, in the embodiment shown in Fig. 2, a normal line of the first surface and a normal line of the second surface are preferably arranged perpendicular to the direction of gravity. This configuration is advantageous when a large photomask or glass plate is used for projection exposure, since the first surface, the second surface, and the concave mirror M_1, which requires the highest accuracy, are not subjected to asymmetric deformations which may occur due to the gravity.

[0033]

Also, in the embodiment shown in Fig. 3, when the optical system is disposed, such that the first surface and the second surface are placed in a horizontal direction with respect to the direction of gravity, the number of the optical devices which may be subjected to asymmetric deformations due to the gravity decreases. Accordingly, it is preferable that the first and second surfaces be disposed horizontally, with the first surface being positioned above the second surface. In particular, this configuration is quite advantageous in terms of optical performances since the elements in the second imaging optical system other than the fifth lens group G5 are not subjected to asymmetric deformations. Here, the feature that the concave mirror M_1 is horizontally arranged with respect to the gravity is particularly effective.

[0034]

Further, in each of the foregoing embodiments, the aperture stop can be disposed near the concave mirror M_1 or in the second imaging optical system (between the fifth lens group G5 and the sixth lens group G6 in particular). Also, in this case, a sigma (σ) value, which is the ratio of the numerical aperture NA of the illumination optical system to the numerical aperture NA of the projection optical system, can be set variable. Most preferably, in these embodiments, the aperture stop

is disposed in the second optical system which is hard to generate a mechanical interference.

[0035]

Also, in place of the aperture stop, various kinds of special filters may be disposed in order to increase the depth of focus. This feature will be explained with reference to Fig. 8 which shows an example of a special filter. The following numerical examples refer to an optical system in which both object and image sides are telecentric while main light rays from respective points on the object side intersect with each other at a certain point in the optical axis. Under this circumstance, a plane including the point at which the main light rays intersect with the optical axis is called a Fourier transform plane. The special filter is disposed on this Fourier transform plane. In the following numerical examples, the Fourier transform plane may be disposed near the concave mirror M_1 or in the second imaging optical system. In the Fourier transform plane, the order of diffracted light is determined by a specific point remote from the optical axis. The order increases as the point is farther from the optical axis. A general projection exposure optical system utilizes zero-order and first-order diffracted light components. Accordingly, as shown in Figs. 8 (a) and 8 (b), the field of the filter is divided into a field FA with a radius r_1 near the optical axis where the zero-order diffracted light component exists and a field FB extending from the radius r_1 to a radius r_2 near the periphery of the aperture where the first-order (or higher-order) diffracted light component exists.

[0036]

As shown in Fig. 8 (c), the concentrically divided filter forms a polarizing film such that its center field FA transmits only S-polarized light while its peripheral field FB transmits only P-polarized light. Of course, it may be configured such that the center field FA transmits only P-polarized light while the peripheral field FB transmits only S-polarized light. Also, the refractive index of the center field FA is set lower than that of the peripheral field FB.

[0037]

According to the above-mentioned configuration, the luminous flux passed through the peripheral field FB of the special filter effects a normal imaging at the focal plane. On the other hand, the luminous flux passed through the center field FA of the special filter forms, due to its lower refractive index, a focal point at a position which is farther from the lens than the normal focal plane is. Here, since the luminous flux which passes through the peripheral field FB and the luminous flux which passes through the center field FA have polarization conditions different from each other, they do not interfere with each other. Accordingly, the depth of focus can be increased. Techniques for increasing the depth of focus are disclosed in Japanese Unexamined Patent Publication No. S61-91662, Japanese Unexamined Patent

Publication No. H5-234850, Japanese Unexamined Patent Publication No. H6-120110, Japanese Unexamined Patent Publication No. H6-124870, Japanese Unexamined Patent Publication No. H7-57992, Japanese Unexamined Patent Publication No. H7-57993, and the like, each of which is applicable to the present invention. These techniques are effective, in particular, when an isolated pattern is to be formed.

[0038]

When the special filter is disposed near the concave mirror M_1, the aperture stop may be disposed in the second imaging optical system so as to change the numerical aperture. Alternatively, the special filter may be disposed in the second imaging optical system, while the aperture stop is disposed near the concave mirror M_1. Thus, in the catadioptric optical system in these embodiments, the aperture stop and the special filter can be disposed in the same optical system while being separated from each other, thereby making it advantageous in terms of spatial arrangement.

[0039]

Also, when a stop is disposed on a place where an intermediate image is formed, this stop may function as a field stop. In the foregoing embodiments, a field stop can be disposed between the first imaging optical system and the second imaging optical system. In the foregoing embodiments, as shown in Figs. 1 to 3, the position for forming the intermediate image is close to the mirror. Accordingly, the stop is preferably disposed near the mirror. A configuration for placing the stop is exemplified by Fig. 9.

[0040]

When the field stop is disposed, as in the case of the example shown in Fig. 9, the optical path bending mirror M_2 is placed as close as possible to the tenth lens group G10 of the first imaging optical system G1. Accordingly, the surface where the intermediate image is formed can be placed nearer to the fifth lens group G5 in the second imaging optical system from the proximity of the optical path bending mirror M_2. According to this configuration, the optical path bending mirror M_2, the tenth lens group G10 of the first imaging optical system G1, and the field stop function are prevented from mechanically interfering with each other. Then, the field stop S is disposed on the surface where the intermediated image is formed. A field where the intermediate image can be formed is changed as the field stop S is moved. Accordingly, an area where the image is finally formed on the second surface is changed.

[0041]

Also, techniques for changing the size of the visual field are disclosed in Japanese Unexamined Patent Publication No. S57-192024, Japanese Unexamined Patent Publication No. S60-30132, Japanese Unexamined Patent Publication No. S60-

45252, Japanese Unexamined Utility Model Publication No. S62-124845, US Patent No. 4,473,293, US Patent No. 4,474,463, and the like, each of which is applicable to the embodiments described here.

[0042]

Alternatively, without moving the movable light-shielding member in response to the circumstances as mentioned above, mirrors with different sizes themselves may be exchanged for each other so as to be used in place of the field stop. Of course, the shape of the field stop having a variable aperture shown in Fig. 9 may be not only square but also of an arc or a polygon having sides larger than the square. Also, since the field stop can be disposed in the projection optical system, a so-called reticle blind disposed in the illumination optical system can of course be eliminated.

[0043]

In the following, numerical examples of the catadioptric optical system in accordance with the present invention will be explained. In the following numerical examples, lens configurations are represented by developed optical path diagrams as shown in Figs. 2 and 4. In the developed optical path diagrams, the reflective surface is represented as a transmissive surface, while the respective optical elements are arranged in the order by which the light from the reticle R passes therethrough. Also, at the reflective surface of the concave mirror, a virtual plane is used. Then, in order to represent the shapes and distances of lenses, for example, as shown in Fig. 2, the pattern surface of the reticle R is defined as a zero surface, while the surfaces through which the light emitted from the reticle R passes before reaching the wafer W are successively defined as i-th surface (i=1, 2, . . .). Here, a radius of curvature r_i of the i-th surface has a plus sign when its convex surface is directed toward the reticle R in the developed optical path diagram. The spacing between the i-th surface and the (i+1)-th surface is defined as d_i. As a glass material, SiO_2 represents fused quartz, whereas CaF_2 represents fluorite. The refractive indices of fused quartz and fluorite at their standard wavelength (193.0 nm) for use are as follows:

fused quartz: 1.56019

fluorite: 1.50138

Also, their dispersion values $1/\nu$ are as follows:

fused quartz: 1,780

fluorite: 2,550

Here, the dispersion values in the examples are those obtained at the standard wavelength (193.0 nm) for use ± 0.1 nm.

[First embodiment]

The first embodiment in accordance with the present invention will be explained with reference to Fig. 2. Fig. 2 is a developed optical path diagram of the catadioptric optical system in the first embodiment.

[0044]

In the lens configuration of lens groups shown in Fig. 2, the seventh lens group G7 includes, in the following order from the side of the reticle R, a biconvex positive lens L_1 which is the eighth lens group G8 and a biconcave negative lens L_2 which is the ninth lens group G9. The third lens group G3 subsequent to the seventh lens group G7 includes a biconvex positive lens L_3 which is the tenth lens group G10; a meniscus negative lens L_4, which is the eleventh lens group G11, whose convex surface faces the reticle R; and a biconvex positive lens L_5 which is the twelfth lens group G12. Further, the fourth lens group G4 subsequent to the third lens group G3 includes a meniscus negative lens L_6, whose concave surface faces the reticle R, and the concave mirror M_1.

[0045]

Here, the luminous flux from the reticle R successively passes through the eighth lens group G8, the ninth lens group G9, the tenth lens group G10, the eleventh lens group G11, the twelfth lens group G12, the fourth lens group G4, the twelfth lens group G12, the eleventh lens group G11, and the tenth lens group G10 so as to form an intermediate image of the reticle R between the third lens group G3 and the seventh lens group G7.

[0046]

The fifth lens group G5 includes, in the following order from the side of this intermediate image, a biconvex positive lens L_7 having a weak refracting power, a biconvex positive lens L_8, a biconcave negative lens L_9, a meniscus negative lens L_{10} whose convex surface faces the intermediate image, a biconcave negative lens L_{11}, a meniscus negative lens L_{12} whose concave surface faces the intermediate image, a biconvex positive lens L_{13}, and a biconvex positive lens L_{14}.

[0047]

Further, the sixth lens group G_6 subsequent to the fifth lens group G_5 includes, in the following order from the intermediate image side, a meniscus positive lens L_{15} whose convex surface faces the intermediate image, a meniscus positive lens L_{16} whose convex surface faces the intermediate image, a meniscus negative lens L_{17} whose concave surface faces the intermediate image, a biconvex positive lens L_{18}, a meniscus negative lens L_{19} whose convex surface faces the intermediate image, a meniscus positive lens L_{20} whose convex surface faces the intermediate image, a biconcave negative lens L_{21} having a weak refracting power, a meniscus negative lens L_{22} whose convex surface faces the intermediate image, and a meniscus positive lens L_{23} whose convex surface faces the intermediate image.

[0048]

In the following Table 1, values of various items in the present embodiment are listed. In this embodiment, the magnification of the whole system is 1/4 (reduction), whereas the numerical aperture NA on the side of the wafer W is 0.57. Also, as shown in Fig. 1, the exposure field on the reticle R in the catadioptric optical system in this embodiment has a rectangular shape in which the longitudinal direction has a length of 24 defined by an object height from the optical axis Ax within the range from 52 to 76 and the transverse direction has a length of 120.

[0049]

In the present embodiment as shown Table 1, the optical path bending mirror M_2 is positioned at the seventh and twenty-eighth surfaces. Further, in the Table 1, the concave mirror M_1 corresponds to the eighteenth surface. In this embodiment, the seventeenth surface (virtual plane) and the eighteenth surface are made as reflective surfaces (refractive index = −1), thereby making it possible to form the developed optical path diagram shown in Fig. 3.

[0050]

TABLE 1

d_0 = 100.000

	r	d	Glass Material
1	608.570	40.000	CaF_2
2	-535.784	35.737	
3	-767.542	15.000	SiO_2
4	583.270	35.000	
5	0.000	20.000	Virtual Plane
6	0.000	15.000	Virtual Plane
7	0.000	67.394	Virtual Plane
8	1932.142	40.000	CaF_2
9	-501.972	223.395	
10	2599.069	15.000	SiO_2
11	491.076	123.036	
12	883.255	30.000	SiO_2
13	-2160.911	187.657	
14	0.000	160.860	Virtual Plane
15	-281.482	15.000	SiO_2
16	-3684.750	70.000	
17	0.000	0.000	Virtual Plane
18	441.367	70.000	Corresponding to Concave Mirror M_1
19	3684.750	15.000	SiO_2
20	281.483	160.860	

21	0.000	187.657	Virtual Plane
22	2160.911	30.000	SiO_2
23	-883.255	123.036	
24	-491.076	15.000	SiO_2
25	-2599.068	223.395	
26	501.972	40.000	CaF_2
27	-1932.142	67.394	
28	0.000	15.000	Virtual Plane
29	0.000	20.000	Virtual Plane
30	0.000	80.000	Virtual Plane
31	3884.731	30.000	SiO_2
32	-1381.698	0.100	
33	391.241	30.000	CaF_2
34	-352.648	5.000	
35	-340.120	24.000	SiO_2
36	348.160	11.200	
37	6861.792	24.000	SiO_2
38	490.913	10.907	
39	865.932	30.000	CaF_2
40	-440.248	3.766	
41	-326.951	35.000	SiO_2
42	-669.448	0.100	
43	490.606	35.000	CaF_2
44	-3123.854	672.921	
45	681.761	40.000	SiO_2
46	-8251.041	8.000	
47	0.000	8.000	Aperture Stop a
48	596.576	45.000	SiO_2
49	664.912	1.260	
50	276.060	72.842	CaF_2
51	12512.845	18.900	
52	-523.686	106.927	SiO_2
53	-728.219	0.513	
54	704.707	33.464	CaF_2
55	-2768.356	0.367	
56	154.151	69.820	SiO_2
57	131.256	12.825	
58	148.970	44.938	SiO_2
59	1416.567	4.200	

60	-1306.088	22.680	SiO_2
61	6140.209	1.920	
62	1077.774	30.410	SiO_2
63	604.397	2.252	
64	326.875	29.808	SiO_2
65	5403.630	15.000	

The condition correspondence values are as follows:

(1) $|Y0/Y1| = 0.97$

(2) $|\beta| = 0.25$

(3) $P4 = -0.00689$

(4) $P3+P5+P6+P7 = 0.00608$

(5) $|P3+P4+P5+P6+P7| = -0.00081$

(6) $|P1+P2| = 0.00000$

Fig. 3 (a) is a diagram showing the longitudinal aberration in the first embodiment; Fig. 3 (b) is a diagram showing the chromatic aberration of magnification in the first embodiment; and Fig. 3 (c) is a diagram showing the transverse aberration in the first embodiment. In each aberration diagram, NA indicates the numerical aperture, whereas Y indicates the image height. Also, marks J, P, and Q respectively indicate wavelengths of 193.0 nm, 192.9 nm, and 193.1 nm. In Fig. 3 (a), a broken line representing the spherical aberration indicates a sine condition infringing amount, whereas a broken line and a checking line representing the astigmatism respectively indicate meridional and sagittal image surfaces. In the transverse aberration diagram shown in Fig. 3 (c), the number written at the upper portion of each coma diagram indicates the object height, and in particular, RAND indicates that the object height is zero.

[0051]

From the various aberration diagrams shown in Figs. 3 (a) to 3 (c), it can be seen that, in this embodiment, while the numerical aperture NA is as large as 0.57, the various aberrations are favorably corrected in a wide range. Also, from the various aberration diagrams shown in Figs. 3 (a) to 3 (c), it can be seen that, in this embodiment, the axial aberration and the chromatic aberration of magnification are favorably corrected within the range of wavelength width of 0.1 nm.

[Second embodiment]

The second embodiment in accordance with the present invention will be explained with reference to Fig. 4. Fig. 4 is a developed optical path diagram of the catadioptric optical system in the second embodiment.

[0052]

The lens configuration of lens groups shown in Fig. 4 includes, in the following order from the side of the reticle R, the tenth lens group G10, the eleventh lens group G11, and the twelfth lens group G12. Here, the tenth lens group G10 includes a biconvex positive lens L_1, a biconcave negative lens L_2, a biconvex positive lens L_3, and a meniscus negative lens L_4 whose concave surface faces the reticle R. Further, the eleventh lens group G11 is a meniscus negative lens L_5 whose convex surface faces the reticle R. The twelfth lens group G12 includes a biconvex positive lens L_6, a meniscus negative lens L_7 whose convex surface faces the reticle R, and a biconvex positive lens L_8. Moreover, the fourth lens group G4 subsequent to the third lens group G3 includes a negative lens L_9 whose concave surface faces the reticle R, and the concave mirror M_1.

[0053]

Here, the luminous flux from the reticle R successively passes through the tenth lens group G10, the eleventh lens group G11, the twelfth lens group G12, the fourth lens group G4, the twelfth lens group G12, the eleventh lens group G11, and the tenth lens group G10 so as to form an intermediate image of the reticle R between the third lens group G3 and the reticle R. The fifth lens group G5 includes, in the following order from the side of this intermediate image, a meniscus negative lens L_{10} whose concave surface faces the intermediate image, a biconvex positive lens L_{11}, a biconcave negative lens L_{12}, a biconvex positive lens L_{13}, and a meniscus negative lens L_{14} whose concave surface faces the intermediate image, a biconvex positive lens L_{15}, and a biconvex positive lens L_{16}.

[0054]

Further, the sixth lens group G6 subsequent to the fifth lens group G5 includes, in the following order from the side of the intermediate image, a meniscus positive lens L_{17} whose convex surface faces the intermediate image, a biconvex positive lens L_{18}, a biconcave negative lens L_{19}, a meniscus positive lens L_{20} whose convex surface faces the intermediate image, a meniscus negative lens L_{21} whose convex surface faces the intermediate image, a meniscus positive lens L_{22} whose convex surface faces the intermediate image, a meniscus negative lens L_{23} whose concave surface faces the intermediate image, a biconvex positive lens L_{24}, and a meniscus positive lens L_{25} whose convex surface faces the intermediate image. Here, the aperture stop "a" is disposed between the fifth lens group G5 and the sixth lens group G6.

[0055]

In the following Table 2, values of various items in the present embodiment are listed. In this embodiment, the magnification of the whole system is 1/4 (reduction), whereas the numerical aperture NA on the side of the wafer W is 0.57. In this embodiment, the exposure field on the reticle R in the catadioptric optical system

has a rectangular shape in which the longitudinal direction has a length of 24 defined by an object height from the optical axis Ax within the range from 48 to 72 and the transverse direction has a length of 120.

[0056]

In Table 2, the concave mirror M_1 corresponds to the twentieth surface. In this embodiment, the nineteenth surface (virtual plane) and the twentieth surface are made as reflective surfaces (refractive index= −1), thereby making it possible to form the developed optical path diagram shown in Fig. 5.

[0057]

TABLE 2

d0 = 218.470

	r	d	n
1	269.428	60.000	CaF_2
2	-309.838	5.000	
3	-287.784	15.000	SiO_2
4	298.252	31.810	
5	319.859	60.000	CaF_2
6	-267.967	4.500	
7	-273.316	20.000	SiO_2
8	-714.458	113.482	
9	1247.366	16.200	SiO_2
10	358.307	83.901	
11	1886.366	25.920	CaF_2
12	-409.348	19.000	
13	-191.202	20.000	SiO_2
14	-460.687	15.474	
15	402.149	33.000	SiO_2
16	-903.948	201.807	
17	-197.350	15.000	SiO_2
18	231563.902	20.000	
19	0.000	0.000	Virtual Plane
20	314.319	20.000	Corresponding to Concave Mirror M_1
21	231563.902	15.000	SiO_2
22	197.350	201.807	
23	903.948	33.000	SiO_2
24	-402.149	15.474	
25	460.687	20.000	SiO_2
26	191.202	19.000	
27	409.348	25.920	CaF_2

28	1886.369	83.901	
29	-358.307	16.200	SiO_2
30	-1247.366	113.482	
31	714.458	20.000	SiO_2
32	273.316	4.500	
33	267.967	60.000	CaF_2
34	-319.859	31.810	
35	-298.252	15.000	SiO_2
36	287.784	5.000	
37	309.838	60.000	CaF_2
38	-269.428	183.470	
39	-227.267	20.000	CaF_2
40	-391.496	3.645	
41	617.033	45.000	SiO_2
42	-292.147	46.222	
43	-259.118	15.000	SiO_2
44	408.199	18.785	
45	1461.463	45.000	CaF_2
46	-250.187	7.000	
47	-223.680	18.000	SiO_2
48	-526.047	56.717	
49	936.544	45.000	CaF_2
50	406.507	590.310	
51	795.462	29.000	SiO_2
52	-1984.285	10.000	
53	0.000	10.000	Aperture Stop a
54	230.009	32.805	SiO_2
55	1447.955	5.000	
56	613.320	35.000	CaF_2
57	-1494.241	7.137	
58	-694.448	40.000	SiO_2
59	478.128	5.000	
60	372.847	48.067	CaF_2
61	2287.239	0.100	
62	100.159	42.562	SiO_2
63	80.943	9.000	
64	86.320	28.964	SiO_2
65	1884.561	4.000	
66	-401.131	17.580	SiO_2

67	-2761.121	0.100	
68	508.419	21.383	SiO_2
69	-577.558	0.100	
70	647.419	15.000	SiO_2
71	3939.247	15.000	

The condition correspondence values are as follows:

(1) $|Y0/Y1| = 0.97$

(2) $|\beta| = 0.25$

(3) $P4 = -0.01$

(4) $P3+P5+P6+P7 = 0.00855$

(5) $|P3+P4+P5+P6+P7| = -0.00145$

(6) $|P1+P2| = 0.00001$

Fig. 5 (a) is a diagram showing the longitudinal aberration in the second embodiment; Fig. 5 (b) is a diagram showing the chromatic aberration of magnification in the second embodiment; and Fig. 5 (c) is a diagram showing the transverse aberration in the second embodiment. In each aberration diagram, NA indicates the numerical aperture, whereas Y indicates the image height. Also, marks J, P, and Q respectively indicate wavelengths of 193.0 nm, 192.9 nm, and 193.1 nm. In Fig. 5 (a), a broken line representing the spherical aberration indicates a sine condition infringing amount, whereas a broken line and a checking line representing the astigmatism respectively indicate meridional and sagittal image surfaces. In the transverse aberration diagram shown in Fig. 5 (c), the number written at the upper portion of each coma aberration diagram indicates the object height, and in particular, RAND indicates that the object height is zero.

[0058]

From the various aberration diagrams shown in Figs. 5 (a) to 5 (c), it can be seen that, in the present embodiment, while the numerical aperture NA is as large as 0.57, the various aberrations are favorably corrected in a wide range. Also, from the various aberration diagrams shown in Figs. 5 (a) to 5 (c), it can be seen that, in this embodiment, the axial aberration and the chromatic aberration of magnification are favorably corrected within the range of wavelength width of 0.1 nm.

[0059]

As described above, according to the embodiments in accordance with the present invention, there can be provided a catadioptric optical system in which, while attaining a very large numerical aperture, the concave mirror M_1 is small and various aberrations are favorably corrected in a wide exposure area. In the first embodiment, the concave mirror M_1 can have a diameter of about 330. In the second embodiment,

the concave mirror M_1 can have a diameter of about 210. Further, in each of these embodiments, the diameters of refractive lenses can be reduced.

[0060]

Also, in the above described embodiments, since the optical path bending mirror M_2, which is used as the optical path deflecting means, is disposed near the intermediate image formed by the first imaging optical system G1, the influence of eccentric errors of the first and second imaging optical systems G1 and G2 upon the optical path bending mirror M_2 can be reduced. Further, in the foregoing embodiments, since the diameter of the luminous flux reaching the reflective surface of the optical path bending mirror M_2 becomes smaller, the size of the optical path bending mirror M_2 itself can be reduced. Accordingly, the luminous flux can be restricted from being shielded due to the optical path bending mirror M_2, thereby advantageously expanding the exposure area.

[0061]

Further, since the foregoing embodiments are advantageous in that, since the luminous flux from the first imaging optical system G1 is deflected by the optical path bending mirror M_2 by 90° and then guided to the second imaging optical system G2, the eccentricities of the first imaging optical system G1 and the second imaging optical system G2 with respect to each other can be easily adjusted. Also, in the foregoing embodiments, since the aperture stop "a" can be disposed between the fifth lens group G5 and sixth lens group G6 in the second imaging optical system G2, when this aperture stop "a" has a variable aperture size, the exposure with variable numerical apertures NA (or variable σ) can be attained.

[0062]

Here, in a case where a beam splitter is used in place of the optical path bending mirror M_1 in the first and second embodiments, collective exposure with the object height on the reticle R from the optical axis Ax within the range of 0 to 72 (to 76 being usable in the first embodiment) can be achieved.

[0063]

Effects of the invention

According to the present invention as described above, the diameter of the concave mirror can be reduced, and a large numerical aperture can be realized while securing a sufficient working distance.

Brief Description of the Drawings

Fig. 1

Fig. 1 is a plan view schematically illustrating a basic configuration of an optical system according to the present invention.

Fig. 2

Fig. 2 is a plan view schematically illustrating another configuration of an optical system according to the present invention.

Fig. 3

Fig. 3 is a plan view schematically illustrating still another configuration of an optical system according to the present invention.

Fig. 4

Fig. 4 is a diagram illustrating a developed optical path of a catadioptric optical system according to a first embodiment of the present invention.

Fig. 5

Fig. 5 is a diagram illustrating various aberrations of the catadioptric optical system according to the first embodiment.

Fig. 6

Fig. 6 is a diagram illustrating a developed optical path of a catadioptric optical system according to a second embodiment of the present invention.

Fig. 7

Fig. 7 is a diagram illustrating various aberrations of the catadioptric optical system according to the second embodiment.

Fig. 8

Fig. 8 is a diagram illustrating an example of a special filter according the embodiment.

Fig. 9

Fig. 9 is a diagram illustrating an example of a field stop according to the embodiment.

Description of Symbols

G1 first imaging optical system
G2 second imaging optical system
G3 third lens group
G10 tenth lens group
G11 eleventh lens group
G12 twelfth lens group
M_1 concave mirror
M_2 optical path bending mirror (optical path deflecting member)
R reticle (first surface)
W wafer (second surface)

Fig. 1
SCANNING DIRECTION
ILLUMINATION RANGE

G1 FIRST IMAGING OPTICAL SYSTEM
G2 SECOND IMAGING OPTICAL SYSTEM
a APERTURE STOP
FIRST SURFACE
SECOND SURFACE
WAFER

Fig. 2
SCANNING DIRECTION
ILLUMINATION RANGE
FIRST SURFACE
SECOND SURFACE
WAFER
G2 SECOND IMAGING OPTICAL SYSTEM
EXPOSURE RANGE
SCANNING DIRECTION
a APERTURE STOP
SCANNING DIRECTION

Fig. 3
ILLUMINATION RANGE
SCANNING DIRECTION
MASK
FIRST SURFACE
SECOND SURFACE
EXPOSURE RANGE
SCANNING DIRECTION
G1 FIRST IMAGING OPTICAL SYSTEM
G2 SECOND IMAGING OPTICAL SYSTEM
a APERTURE STOP
WAFER

Fig. 5
(a)
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
(b)
CHROMATIC ABERRATION OF MAGNIFICATION

(c)
TRANSVERSE ABERRATION

Fig. 7
(a)
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
(b)
CHROMATIC ABERRATION OF MAGNIFICATION
(c)
TRANSVERSE ABERRATION